New material acts as an efficient frequency multiplier

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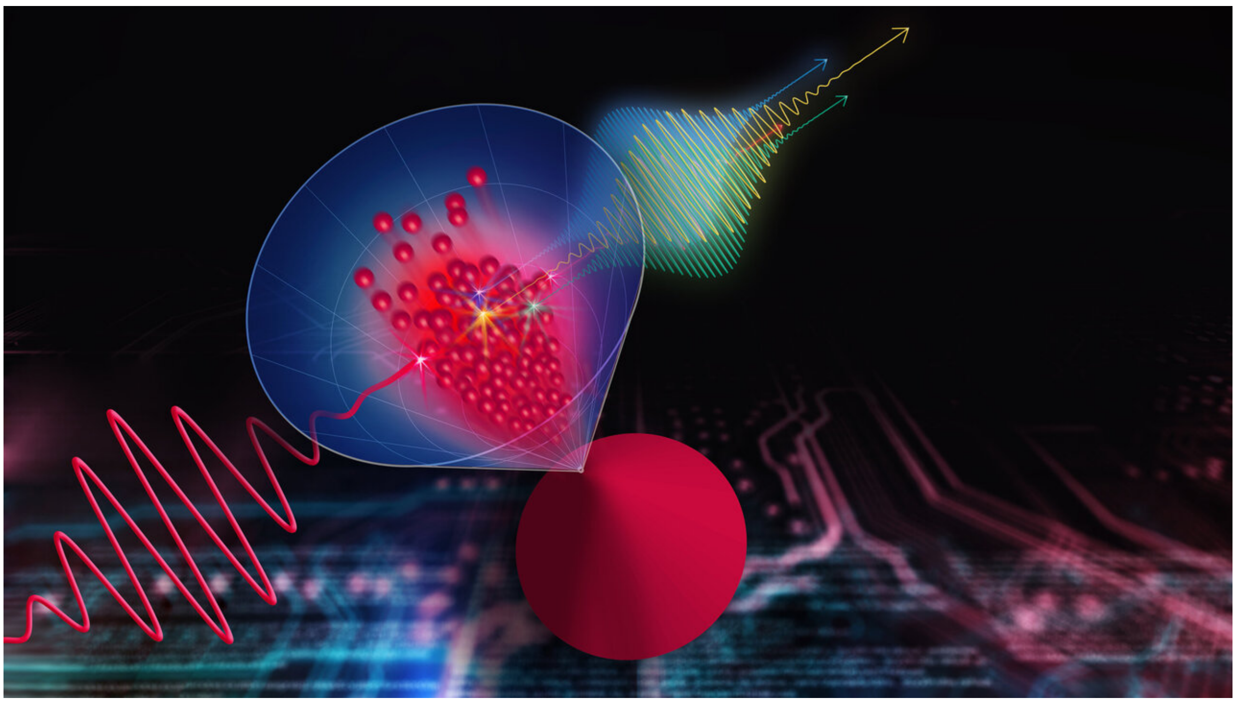

An international team of researchers was able to show that the three-dimensional Dirac material cadmium arsenide (blue-red cone) can multiply the frequency of a strong terahertz pulse (red line) by a factor of seven. The reason for this are the free electrons (red dots) in the cadmium arsenide, which are accelerated by the electrical field of the terahertz flash and, thus, in turn emit electromagnetic radiation. Credit: Helmholtz-Zentrum Dresden-Rossendorf

Higher frequencies mean faster data transfer and more powerful processors—the formula that has been driving the IT industry for years. Technically, however, it is anything but easy to keep increasing clock rates and radio frequencies. New materials could solve the problem. Experiments at Helmholtz-Zentrum Dresden-Rossendorf (HZDR) have now produced a promising result: An international team of researchers was able to get a novel material to increase the frequency of a terahertz radiation flash by a factor of seven: a first step for potential IT applications, as the group reports in the journal *Nature Communications*.

When smartphones receive data and computer chips perform calculations, such processes always involve alternating electric fields that send electrons on clearly defined paths. Higher field frequencies mean that electrons can do their job faster, enabling higher data transfer rates and greater processor speeds. The current ceiling is the terahertz range, which is why researchers all over the world are keen to understand how terahertz fields interact with novel materials. "Our TELBE terahertz facility at HZDR is an outstanding source for studying these interactions in detail and identifying promising materials," says Jan-Christoph Deinert from HZDR's Institute of Radiation Physics. "A possible candidate is cadmium arsenide, for example."

The physicist has studied this compound alongside researchers from Dresden, Cologne, and Shanghai. Cadmium arsenide (Cd_3As_2) belongs to the group of so-called three-dimensional Dirac materials, in which electrons can interact very quickly and efficiently, both with each other and with rapidly oscillating alternating electric fields. "We were particularly interested in whether the cadmium arsenide also emits terahertz radiation at new, higher frequencies," explains TELBE beamline scientist Sergey Kovalev. "We have already observed this very successfully in graphene, a two-dimensional Dirac material." The researchers suspected that cadmium arsenide's three-dimensional electronic structure would help attain high efficiency in this conversion.

In order to test this, the experts used a special process to produce ultra-thin high-purity platelets from cadmium arsenide, which they then subjected to terahertz pulses from the TELBE facility. Detectors behind the back of the platelet recorded how the cadmium arsenide reacted to the radiation pulses. The result: "We were able to show that cadmium arsenide acts as a highly effective frequency multiplier and does not lose its efficiency, not even under the very strong terahertz pulses that can be generated at TELBE," reports former HZDR researcher Zhe Wang, who now works at the University of Cologne. The experiment was the first ever to demonstrate the phenomenon of terahertz frequency multiplication up to the seventh harmonic in this still young class of materials.

Electrons dance to their own beat

In addition to the experimental evidence, the team together with researchers form the Max Planck Institute for the Physics of Complex Systems also provided a detailed theoretical description of what occurred: The terahertz pulses that hit the cadmium arsenide generate a strong electric field. "This field accelerates the free electrons in the material," Deinert describes. "Imagine a huge number of tiny steel pellets rolling around on a plate that is being tipped from side to side very fast."

The electrons in the cadmium arsenide respond to this acceleration by emitting electromagnetic radiation. The crucial thing is that they do not exactly follow the rhythm of the terahertz field, but oscillate on rather more complicated paths, which is a consequence of the material's unusual electronic structure. As a result, the electrons emit new terahertz pulses at odd integer multiples of the original frequency—a non-linear effect similar to a piano: When you hit the A key on the keyboard, the instrument not only sounds the key you played, but also a rich spectrum of overtones, the harmonics.

For a post 5G-world

The phenomenon holds promise for numerous future applications, for example in wireless communication, which trends towards ever higher radio frequencies that can transmit far more data than today's conventional channels. The industry is currently rolling out the 5G standard. Components made of Dirac materials could one day use even higher frequencies—and thus enable even greater bandwidth than 5G. The new class of materials also seems to be of interest for future computers as Dirac-based components could, in theory, facilitate higher clock rates than today's silicon-based technologies.

But first, the basic science behind it requires further study. "Our research result was only the first step," stresses Zhe Wang. "Before we can envision concrete applications, we need to increase the efficiency of the new materials." To this end, the experts want to find out how well they can control frequency multiplication by applying an electric current. And they want to dope their samples, i.e. enrich them with foreign atoms, in the hope of optimizing nonlinear frequency conversion.

More information: Sergey Kovalev et al, Non-perturbative terahertz high-harmonic generation in the three-dimensional Dirac semimetal Cd_3As_2, *Nature Communications* (2020). DOI: 10.1038/s41467-020-16133-8

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